Final Report for ONR Contract N00014-87-K-0059

1987

Summary of Work Accomplished

Most of the effort was directed towards an application of modern techniques of nonlinear physics to problems in magnetism at the level of classical magnetization fields. That effort was distributed as follows: 1) high power ferromagnetic resonance, 2) chaotic motion of ferromagnetic domain walls, 3) morphology of domain structures in subsaturating magnetic fields, 4) self-organized critical states of domain wall configurations.

1. We have cleared up a long-standing mystery in ferromagnetic resonance: the observed auto-oscillations of the magnetization field under large applied microwave power.[1] Accompanying these oscillations we predict characteristic spatial autocorrelation patterns of the magnetization. At least one group of experimentalists (at Recife, Brazil) is planning to look for such patterns. These results, which were established using the so-called 'center manifold' theory of nonlinear dynamics were reported in an invited paper at one of the annual Magnetism and Magnetic Materials Conferences.

2. The motion of a Bloch domain wall driven by an oscillatory magnetic field was found to go chaotic in computer simulations,[2] if a certain critical inequality involving the intrinsic damping rate of the magnetic material and frequency and amplitude of the driving field was satisfied. This result suggests that a quantity analogous to the Reynolds number of fluid mechanics may be established for domain wall motion.

3. We have found exact general solutions of the micromagnetics equations for Domain configurations in soft magnetic materials below saturation in two-dimensional, or effectively two-dimensional, cases.[3] The results convincingly illustrate the generally accepted notion that a magnetic sample of macroscopic dimensions can take on any one of a huge number of domain structures.[4] Experimental confirmation of one of our results (a thin disc in a magnetic field in the plane of the disc) was obtained by a group of investigators and reported in paper HQ-02 at the Intermag Conference 1990 in Brighton, England.

4. In the latter half of the final year of this contract period we established that domain structures tend to prefer to arrange themselves in 'only just' metastable states, so-called self-organized critical states.[5] The response of these to perturbations are characterized by certain scaling laws. We analyzed in detail (using a simple cellular automata algorithm) the case of a so-called zig-zag domain wall in a recording tape, and found the corresponding scaling law. The statistical features of our computed zig-zag walls are in good agreement with observations. This subject is of major importance for recording noise considerations and for problems such as erasability of recording media.

Other nonlinear phenomena that were studied under this contract were: a) general reaction kinetics, b) critical transitions of incommensurate structures, and c) nonlinear regimes in cyclotron resonance in metals.

a) Conventional reaction kinetics is based on the assumption that the degrees of freedom of the reactants move slowly compared with the degrees of freedom of the thermal reservoir. In many situations (particularly in heterogeneous catalysis) this premise is not fulfilled. It then becomes necessary to discuss the problem in phasespace, not just as a problem in escape over barriers in configuration space as in the conventional theory.[6]

b) Dynamical systems moving under more than one spatially periodic force with incommensurate periods can undergo commensurate-incommensurate transitions characterized by a certain scaling law. We have discussed a certain anomaly in the scaling for a particular region in the parameter space of this problem.[7]

c) Large signal cyclotron resonance in metals should exhibit interesting effects that are perfect 'textbook' illustrations of some basic principles of nonlinear dynamics. The effects in question were evaluated in terms of parameters appropriate to the Fermi surface of simple metals, and prospects for experimental verification were discussed.

References

1. H. Suhl and X.Y. Zhang, "Spin Wave Instabilities and their Revival by Nonlinear Mechanics," 32nd Annual Conf. on Magnetism and Magnetic Materials, Chicago, Ill., 9-12 November 1987. *J. Appl. Phys.* **63**, 4147 (1988); X.Y. Zhang and H. Suhl, "Theory of Auto-Oscillation in High Power Ferromagnetic Resonance," *Phys. Rev. B* **38**, 4893 (1988).

2. H. Suhl and X.Y. Zhang, "Chaotic Motion of Domain Walls in Soft Magnetic Materials," *J. Appl. Phys.* **61**, 4216 (1987).

3. P. Bryant and H. Suhl, "Magnetization and Domain Structure of Cylinders and Spheres in Subsaturating Fields," *Appl. Phys. Lett.* **54**, 78 (1989); P. Bryant and H. Suhl, "Thin Film Magnetic Patterns in an External Field," *Appl. Phys. Lett.* **54**, 2224 (1989); H. Suhl and P. Bryant, "The Nonlinear Horrors of Realistic Magnetization Fields," in *Magnetic Phenomena: The Warren E. Henry Symposium on Magnetism, in Commemoration of His 80th Birthday and His Work in Magnetism, Washington, DC, August 15-16, 1988*, Lecture Notes in Physics, Vol. 337, edited by A.P. Maclin, T.L. Gill, and W.W. Zachary (Springer-Verlag, Berlin, 1989), pp. 59-73; Paul Bryant and Harry Suhl, "Micromagnetics Below Saturation," *J. Appl. Phys.* **66**, 4329 (1989).

4. H. Suhl, "Pattern Formation and Self-Organization in Magnetic Systems," in *New Trends in Magnetism*, Proceedings of Conf., Recife, Brazil, 26-28 July, 1989, eds. Mauricio D. Coutinho-Filho and Sergio M. Rezende (World Scientific, Teaneck, NJ, 1989).

5. Xiaodong Che and Harry Suhl, "Magnetic Domain Patterns as Self-Organizing Critical Systems," *Phys. Rev. Lett.* **64**, 1670 (1990).

6. H. Suhl, "Escape Over Barriers in Almost Integrable Systems," *Phys. Rev. Lett.* **60**, 473 (1988).

7. H. Johannesson, B. Schaub and H. Suhl, "Critical Exponents for an Incommensurate Structure with Several Length Scales," *Phys. Rev. B* **37**, 9625 (1988).

STATEMENT "A" per Dr. Michael Shlesinger
ONR/Code 1112, Title should be:"Large
Motions of the Magnetization in Magneti-
cally Ordered Media"
TELECON 8/29/90 VG

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
for
1 Oct 88 through 30 Sept 89

R&T Number: 4123033

Contract/Grant Number: N00014-87-K-0059

Contract/Grant Title: Large Motions of the Magnetization in Magnetically Ordered Media

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a. Number of Papers Submitted to Refereed Journal but not yet published: 2

b. Number of Papers Published in Refereed Journals: 4
(list attached)

c. Number of Books or Chapters Submitted but not yet Published: 2

d. Number of Books or Chapters Published: 1
(list attached)

e. Number of Printed Technical Reports & Non-Refereed Papers: 0
(list attached)

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0
(list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 2

i. Number of Presentations at Workshops or Prof. Society Meetings: 0

j. Honors/Awards/Prizes for Contract/Grant Employees: 0
(list attached, this might include Scientific Soc Awards/Offices, Promotions, Faculty Awards/Offices etc)

k. Total number of Graduate Students and Post-Docs Supported at least 25% this year on this contract/grant:

Grad Students 2 and Post-Docs 1.

How many of each are females or minorities? (These 6 numbers are for ONR's EEO/Minority Reports; minorities include Blacks, Aleuts AmIndians, etc and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting the varying report semantics re "economically disadvantaged").

Grad Student Female _____

Grad Student Minority _____

Grad Stu Asian e/n 2

Post-Doc Female _____

Post-Doc Minority _____

Post-Doc Asian e/n _____

Papers Published in Refereed Journals:

1. Suhl, H., "Cyclotron Resonance Revisited." *J. Phys. (Paris)* **50**, 2613 (1989).

2. Bryant, P., and H. Suhl, "Thin Film Magnetic Pattersn in an External Field." *Appl. Phys. Lett.* **54**, 2224 (1989).

3. Bryant, P., and H. Suhl, "Magnetization and Domain Structure of Cylinders and Spheres in Subsaturating Fields." *Appl. Phys. Lett.* **54**, 78 (1989).

4. Bryant, Paul Henry, "Parametric Excitation of Walker Modes in Ferromagnetic Spheres." *Phys. Rev. B* **39**, 4363 (1989).

Books or Chapters Published:

1. Suhl, H. and P. Bryant, "The Nonlinear Horrors of Realistic Magnetization Fields," In *Magnetic Phenomena: The Warren E. Henry Symposium on Magnetism, in Commemoration of His 80th Birthday and His Work in Magnetism, Washington, DC. August 15-16, 1988*, Lecture Notes in Physics, Vol. 337, edited by A.P. Maclin, T.L. Gill, and W.W. Zachary (Springer-Verlag, Berlin, 1989), pp. 59-73.